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POWER DIVISION

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RECENT TRENDS IN HYDRAULIC GATE DESIGN

D. A. Buzzell,[1] M. ASCE

SYNOPSIS

In the past eight years the Corps of Engineers, anticipating its requirements for hydraulic gates of exceptional size and exacting serviceability, has developed and tested several types of sluice, crest and intake gates, some of which are novel in design or application. All of the gates described in this paper, with the exception of the skimming tainter gate, have proven in service to be satisfactory from an engineering standpoint.

The most successful gates from a practical standpoint are an improved hydraulically-operated slide gate which has been operated under 285 feet of head, and an eccentric trunnion tainter sluice gate designed for 200 feet of head.

The writer believes that the new gate developments described in this paper have made important contributions to engineering knowledge and practice and that they should be called to the attention of the profession.

INTRODUCTION

The past 10 years have witnessed some striking advances in hydraulic gate design as practiced by the Corps of Engineers. These advances were brought about by real demands on our designers arising from project conditions, rather than from any desire to set records. They were not made recklessly but only after much experimentation and model testing. At times, however, it was requisite that a bold decision regarding the use of some of these devices be made. It seems amusing now that as late as 1946 we firmly believed that no greater depth of water than about 25 feet could be discharged over an ogee spillway without shaking the structure to pieces, and that sluice gates could not be long operated under heads exceeding 100 feet without being destroyed by cavitation and erosion. Both of these figures have been more than doubled recently without any harmful consequences. Quite a few other so-called criteria regarding the size and use of crest, intake, and sluice gates have been discarded during this period. At the present time we can say that there are no arbitrary limitations on the size or operating head for any type of gate except possibly for the hydraulic slide gate.

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Recent Trends in Hydraulic Gate Design

In 1946-47 the Corps of Engineers conducted a nationwide survey of all known and accessible hydraulic gates including those built and operated by other agencies and by private corporations. The purpose of this survey was to determine, insofar as possible, what the operating experience had been for various types of gates and also which types were best suited for specific conditions. It was known at the time that many diverse opinions, and partly-substantiated criteria, were current among engineers concerned with this field, and the survey was launched with considerable optimism that all bothersome questions would be answered and that henceforth the Corps would make no errors either in choice of gate type or in the detailed design of the type chosen. We were particularly interested in high-head gates capable of part-open operation in closed conduits.

Unfortunately the results of this survey were at the time rather inconclusive. Almost every type of gate has been used at some time to control water under almost every possible condition. Butterfly gates, usually employed as a shutoff valve for penstocks, had proven successful as free-discharge sluice gates under high head at Ross Dam, and many roller-train gates of the Broome or similar types were serving with varying success as high-head sluice gates in conduits. The reports on slide gates showed the frequent occurrence of erosion, cavitation and vibration of the gates. The tainter gate had been suggested as one with desirable hydraulic properties for high-head discharge, but at the time no such use of the gate had been attempted in the States. The Stoney gate, the cylinder gate, and many varieties of needle valve had already piled up impressive records of excessive maintenance costs which were verified during the survey, and none of these gates has been employed in Corps' projects for the past 15 or 20 years.

In 1946 we were planning several projects in which it was apparent that high-head gates of unusual size or application would be required. Spurred by necessity, and dissatisfied with information obtained from the survey, we undertook a series of full-scale tests on slide and tainter gates. The first of these tests was performed on a 4 foot by 6 foot sluice gate at Norfork Dam. Eventually we developed a new sluice slide gate suitable, in small sizes, for use at any gate opening under heads as high as 200 feet or more and a sluice tainter gate suitable for the same usage but practically unlimited in size. The slide gate was described in a paper given by J. H. Douma before the Fourth Large Dams Conference in Delhi and the tainter gate by the same author in an ASCE paper at the last annual meeting. I will, therefore, review them only briefly at this time. Essentially the improvements accomplished by the Norfork slide gate tests were a reshaping of the gate bottom contour and bevelling of the downstream faces of the gate guides. The tainter gate tests at Norfork were a demonstration rather than a new development. We did, however, prove that either with expandible rubber seals or by using solid rubber seals and traversing the gate to and fro by means of an eccentric trunnion a satisfactory closure could be made.

The Norfork Slide Gate

The slide gate, with a cast steel body operated by means of a hydraulic cylinder, is the most versatile of all high-head gates up to a size of about 6 by 10 feet. We have several hundred of them in use and since the development of the Norfork type, described by Mr. Douma, they have proven uniformly satisfactory for continuous operation at any opening under heads up to at least 200 feet. One gate has actually been successfully operated at 285-foot head. The standard slide gate will cost between $400 and $500 per square foot installed which makes it too costly for indiscriminate use.

Practical limitations on the size of cylinder and intensity of oil pressure make 6' by 10' the maximum size for this gate. Such a size limitation often makes this type of gate unsuitable for our larger conduits. Slide gate bodies are still made of cast steel. Attempts to make them of welded steel plates have so far proven economically impracticable.

The Garrison Tainter Gate

The Garrison tainter gate is 18 feet wide and 24.5 feet high with a head of 169 feet so that the total water thrust is 4,700,000 pounds, and yet only one 7.5 H.P. motor is required for operation. This design was model-tested at Vicksburg and further tested in a 4-foot by 6-foot model under 182-foot head at Norfork Dam. The three Garrison gates have now been installed and have been tested under 80 feet of head. Operation is entirely satisfactory.

At Garrison it was desired to control the discharge of a 22-foot diameter conduit with a single gate and to regulate the flow to any degree of fineness without risking cavitation or erosion. The tainter gates have accomplished this at a cost comparable to that of an equivalent area of small standard slide gates.

While we have every reason to believe that this gate will be entirely satisfactory for its intended task of discharging up to 25,000 second feet of water without vibration of the gate or damage to the gate or conduit, it is now felt that the hydraulically-actuated rubber seals mounted on the gate frame are unnecessarily elaborate and costly. We have already developed, tested and built an improved and much less costly version of the high-head tainter valve for Lookout Point Dam.

The Lookout Point Tainter Sluice

One of the series of tests at Norfork had shown that it was quite practicable to move a tainter gate transversely against a solid rubber sealing frame by the use of an eccentric trunnion mounting. There were strong indications that the water passages below the gate frame should be abruptly enlarged not only to provide a mounting for the seal but also to provide ample aeration for the water jet. In this fashion almost free discharge conditions are secured. This type of gate mounting is much simpler than the Garrison design, both structurally and hydraulically, and the initial cost proved to be much lower. At Lookout Point it was desired to use a sluice gate somewhat larger than the largest practicable slide gate for a head of 200 feet. The gate finally developed is

6' -9" by 12' -0" and it is mounted on a power-operated eccentric trunnion which enables the operator to withdraw the gate to clear the frame-mounted solid rubber seals before raising or lowering. This clearance eliminated rubbing friction and makes it possible to operate the gate with a small, although exceedingly long, hydraulic cylinder. The hydraulic cylinder is more suitable than a mechanical device because it tends to dampen out small oscillations of the gate itself. The gap at the seal allows a tremendous shower of spray to form in the chamber below the gate during movements, but this has proven to be more spectacular than harmful.

The seals of this gate consist of a uniform section of hard rubber securely clamped to all four sides of the gate mounting like a picture frame. Rotation of the eccentric trunnion through the beveled gear train moves the gate backwards or forwards through a total movement of one-half inches. The eccentric member of the trunnion is mounted between inner and outer roller bearings which takes the entire thrust of about 1,000,000 pounds. The traversing mechanism is driven by means of a 15 H.P. motor. The gate is opened and closed by means of a 7-5/8" diameter oil cylinder which acts on a cross-head moving in fixed guides. The oil pump motor is also 15 H.P.

In operation, the eccentric withdraws the gate to clear the seals, the required vertical movement is made, and then the gate is moved forward to clamp firmly against the seals. With the gate securely clamped vibration cannot be set up and in fact there is no perceptible vibration under any operating condition. In the unsealed position water jets freely through the seal gap and fills the gate chamber with spray but this condition lasts only a few minutes and the operator is protected by a concrete and steel enclosure.

One of the attractive features of this gate is its low cost - about $90 per square foot of gate opening or 20 per cent of the cost of a standard slide gate. Another distinct advantage lies in the possibility of making this gate much larger than the largest practicable slide gate. Since we have encountered no difficulty in designing tainter gates with total thrusts of 4,000,000 pounds using plain, instead of roller, trunnions it would seem that by using a somewhat heavier eccentric-operating mechanism we might well quadruple the area of this gate before running into mechanical difficulties. There is no reason why gates of this type should not prove to be feasible up to 300 square feet in area and for 300 feet or more of head.

Detroit Dam Fixed Roller Vertical Lift Gate

At about the same time the Meridian tainter gate was undergoing development our 400' high Detroit Dam was also being planned. Ordinarily we would use three tiers of standard slide gates in a dam of this height so that operation of the gates would not have to be undertaken at heads exceeding about 100 feet. Flood routing and stream regulation here demanded possible sluice operation at any reservoir level. Certain tests, including those at Norfork Dam led us to believe that, if mechanical difficulties could be overcome, we could design the slide gate to operate at 200' head and so be able to eliminate one entire tier of gates. The gate dimensions are our standard 5' -8" x 10' -0".

Sliding friction is the limiting factor in slide gate design so we made use of fixed rollers and this in turn dictated the use of a welded plate gate body. The seals are a standard "J" solid rubber section for top and sides. This gate has been entirely successful in operating at any gate opening up to 285'. The necessity of using a welded-plate gate body has, however, made this a rather costly gate and it is certain that the design will not be repeated. The discharge capacity if 7,000 cfs. The eccentric trunnion tainter gate is far more suitable and economical for this type of location.

McNary Intake Gates

At McNary Dam, on the Columbia River, a novel solution was attempted for the problem of a very large penstock intake gate. In order to supply 15,000 cfs of water to the 110,000 H.P. Kaplan wheels a gate opening 20' wide and 51' high was required. This presented no structural problem, as gates have been built to greater widths for the 107' head involved. It did offer an opportunity to facilitate operation by providing, at low cost, means for quickly closing any gate without using the traveling gantry crane.

These are standard roller train gates with rubber seals. Each gate body consists of five units so joined together that the gate body as a whole is semi-flexible, to compensate for inequalities of track and so permit even bearing under load. Each gate is suspended from a fixed lifting beam through two hydraulic cylinders with safety dogs to prevent involuntary gate drop. The gates hang just high enough to clear the water passage and any gate can be quickly lowered by the operation of two oil valves. When it is necessary to work on a gate the gantry crane is employed to withdraw the entire gate and beam assembly. Thus individual gate operation is secured and at a fraction of the cost of individual hoists. Ordinarily two large cranes would have been used for a 20-unit powerhouse of this type. As designed, one crane can be eliminated and this alone more than pays for the extra cost of the beams and cylinders.

Modern Tainter Gate

The tainter gate has undergone a minor revolution in design and usage. The then well-designed tainter crest gate used for Caddoa Dam in the mid-thirties, though using low-alloy steel at 27,000 psi, was overly heavy and the lavish use of curved plates and surfaces made it rather costly. The anchorages were eye-bars securing a 20" diameter trunnion pin 14' long which was subjected to heavy bending stresses. The tainter gate which has been evolved during the past few years has a gate body, made of carbon steel, and with inclined end frames it is lighter and moreover of no more complexity than an average bridge structure. The anchorage is a continuous, doubly-overhung box girder to which the anchor girders are welded. A typical gate, 40' wide by 38.5' high, costs about $37.00 per square foot including hoists. It is operated by means of a 7.5 H.P. motor which, by means of a high-speed countershaft lifts both ends of the gate simultaneously. We have built larger tainters up to 40' x 50' and now have several hundred planned or in operation. Our tainter crest gates are now well standardized in a simple design with a

minimum number of members and full advantage taken of continuity. The weight is low and bid prices are usually little higher than those for average bridge steel. We are now investigating the use of post-tensioning for gate anchorages. By simply anchoring the usual trunnion girder to the concrete pier by means of long high-strength steel bars or wire cables it should be possible to eliminate 75 percent of the weight and 60 percent of the cost of the heavy anchorages.

Large Vertical Lift Roller Train Gates

It has been found that a single gate of the vertical lift type is more economical than two or more, at least for sizes up to 18' wide by 25' high under high heads. This angle of gate economics has been explored quite fully. We therefore, invariably use one gate for each power intake. For outlet sluices, however, it is desirable to have at least three gates so that some discharge capacity will be available even though one gate is out of commission. Where there are three or more outlet tunnels or sluices we can, however, take advantage of the economy of a single gate leaf. The Ft. Randall 11' x 23' roller train sluice gate can be taken as an example. This is a welded body gate with the improved Norfork-type bottom shape. Hitherto these large, high-head gates have been built with nearly square bottoms because the designers considered that this shape was demanded by structural considerations. The Randall gate was designed with a 45 degree sloped bottom member made of cast steel in order to minimize downpull due to low pressure areas at this point with the gate part-open. This innovation has proved to be practicable structurally and the gate operates perfectly at all normal heads. During diversion, when the gate was operated at abnormally low heads, some vibration occurred due to the fact that upstream pressure was insufficient to secure the gate against the guides. Seals are of solid rubber.

New Skimming Tainter Gate

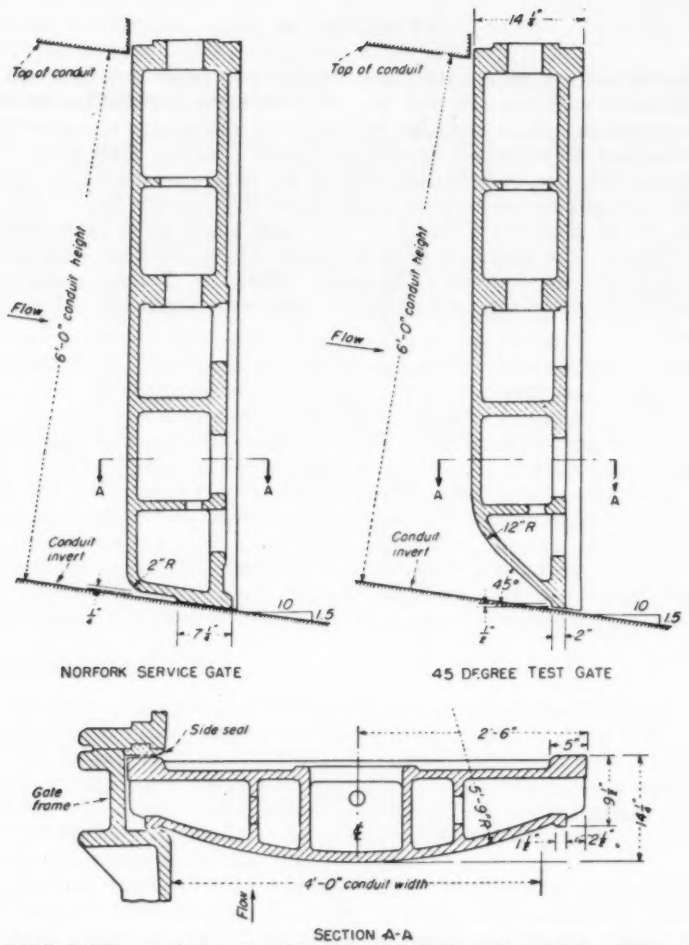
In connection with studies of the proposed new navigation locks for the Ohio River, it was found that several spillway gates of about 100' span by 36' height would be required. As considerable time was available for planning, some extensive economic studies were made of single and double vertical lift, and of Mississippi River type rolling gates. The double vertical lift gate has been favored up to now, but recently studies were undertaken of a double-leaf tainter gate.

The problem was to provide a skimmer gate which could be lifted to a great height to clear floods. Skimming was requisite in order to pass ice and drift and at the same time conserve water for a future power plant. By placing a fixed cable or chain hoist high on the upstream end of the gate pier and running the hoist cable over a set of fixed rollers mounted on a circular segment, it was possible to maintain a fixed-position hoist line. After passing over this segmental roller bed the cable extends to an idler mounted on a trolley which also moved on a segment track. After passing over this idler the hoist line drops vertically to the tainter gate. The final result of this indirect rigging is that the hoist line to the gate is always vertical and the required pull on the line is almost constant - varying only with the water pressure friction.

Minimized hoist loads for these large gates is highly desirable. The skimming action of this gate is secured by over-running the hoist in the gate - closed position - the weight of the separate skimming leaf lowering it the desired amount.

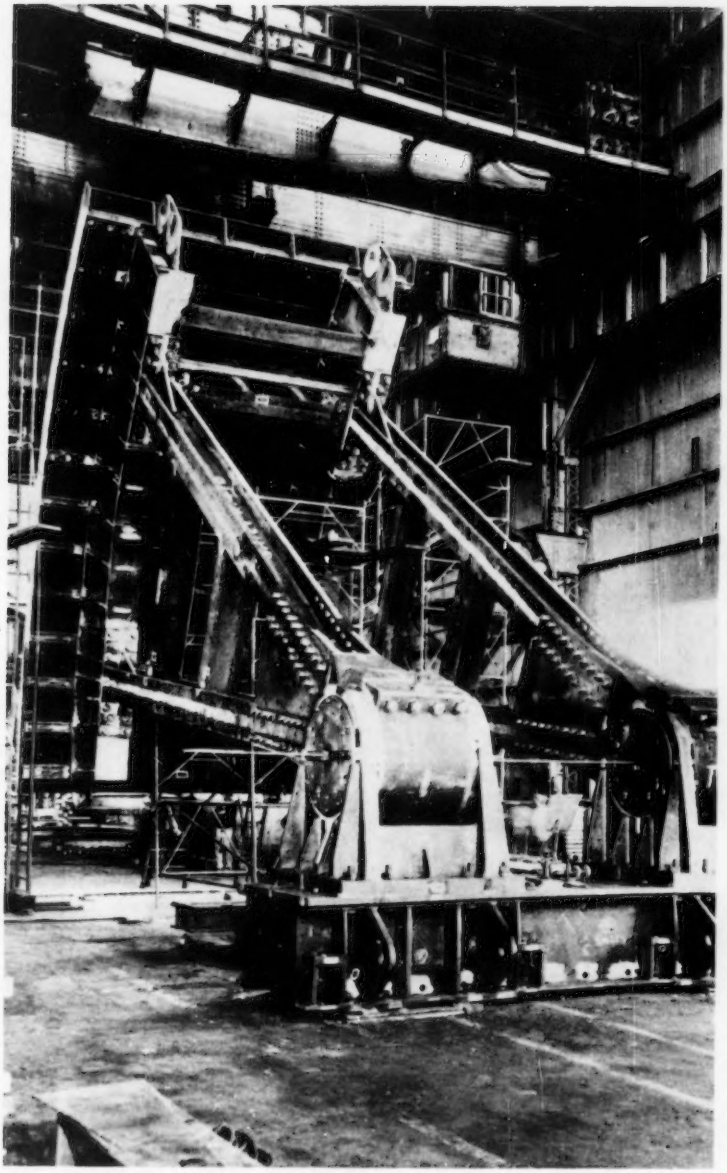
CONCLUSIONS

On the basis of information presented in this paper it is believed that the fields of usefulness of both the hydraulic slide gate and the eccentric tainter gate have been extended by the Corps of Engineers' research and development work carried on during the past 8 years. Slide gates of moderate size can be designed to serve for part-open discharge under high heads without adverse hydraulic or mechanical effects. Tainter gates can be used economically as high-head sluice gates up to large dimensions. The operation of large power intake gates has been simplified by the use of auxiliary hydraulic cylinders. Several useful innovations in gate design and operation have been developed and proven in use.



SLIDE GATE with 45-deg. sloped bottom edge eliminated cavitation noises and effected a great reduction in vibration when tested at partial openings under 160-ft. head in an outlet conduit at Norfork Dam.

Fig. 1. Development of Norfork Slide Gate



GARRISON RESERVOIR, NORTH DAKOTA
Corps of Engineers, Garrison District, Fort Lincoln, Bismarck, North Dakota

PROJECT Regulating Gates F. C. GEN CONTRACT NO. DA-32-015-eng-1551, dtd 13 July 1951
CONTRACTOR Consolidated Western Steel Corp., Los Angeles, California
LOCATION & SUBJECT Contractor's shop. Complete shop assembly for testing purposes.

Date of Photo 17 February 1953 Photo No. 8499

Fig. 2. The Garrison Sluice Gate

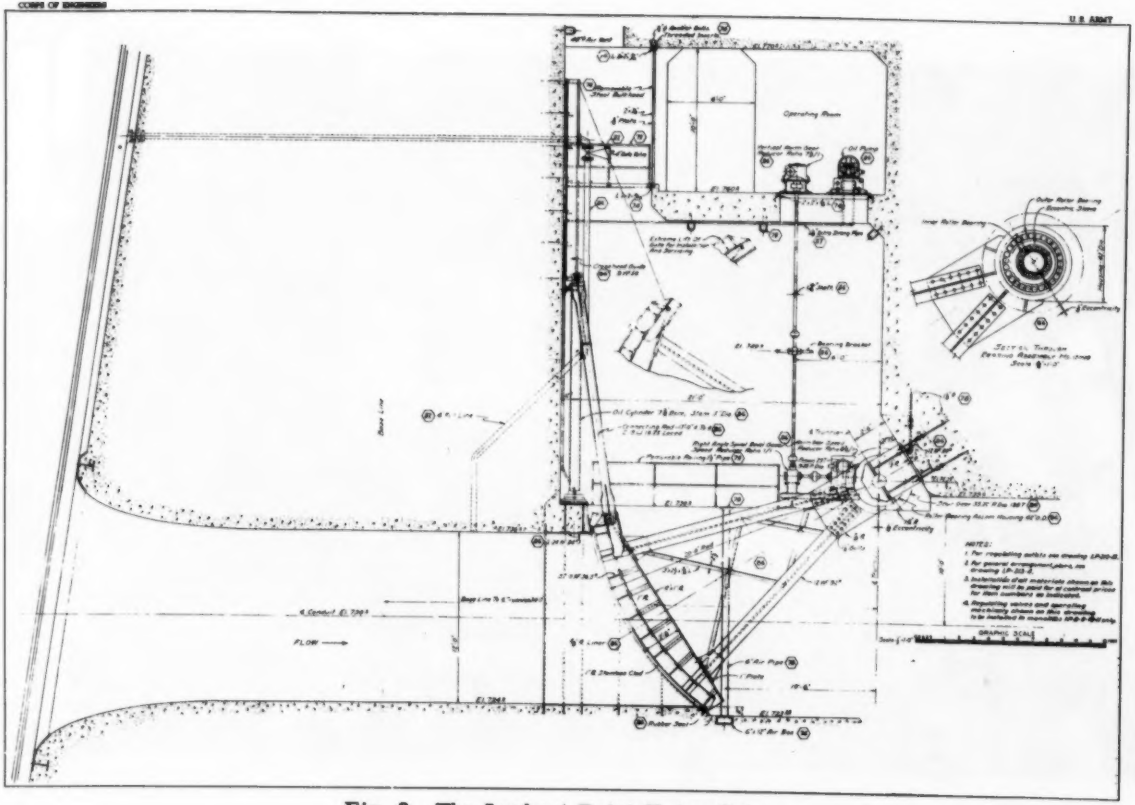


Fig. 3. The Lookout Point Sluice Gate

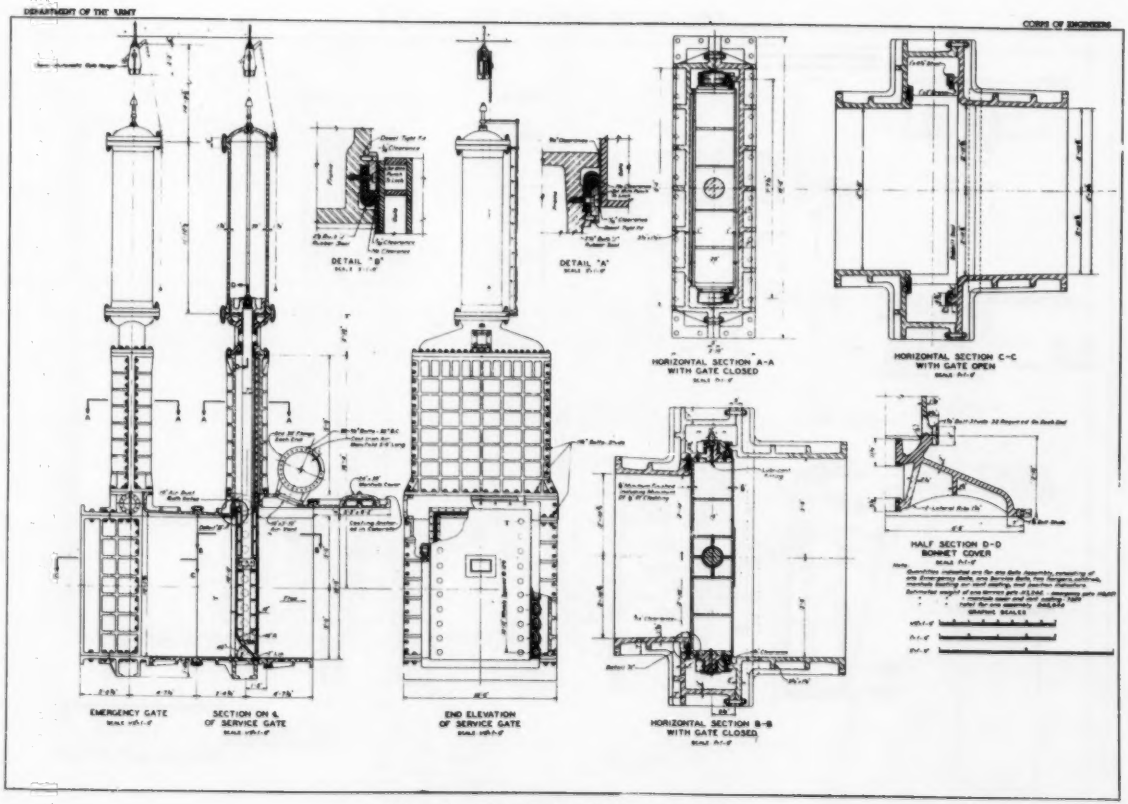


Fig. 4. The Detroit Sluice Gate

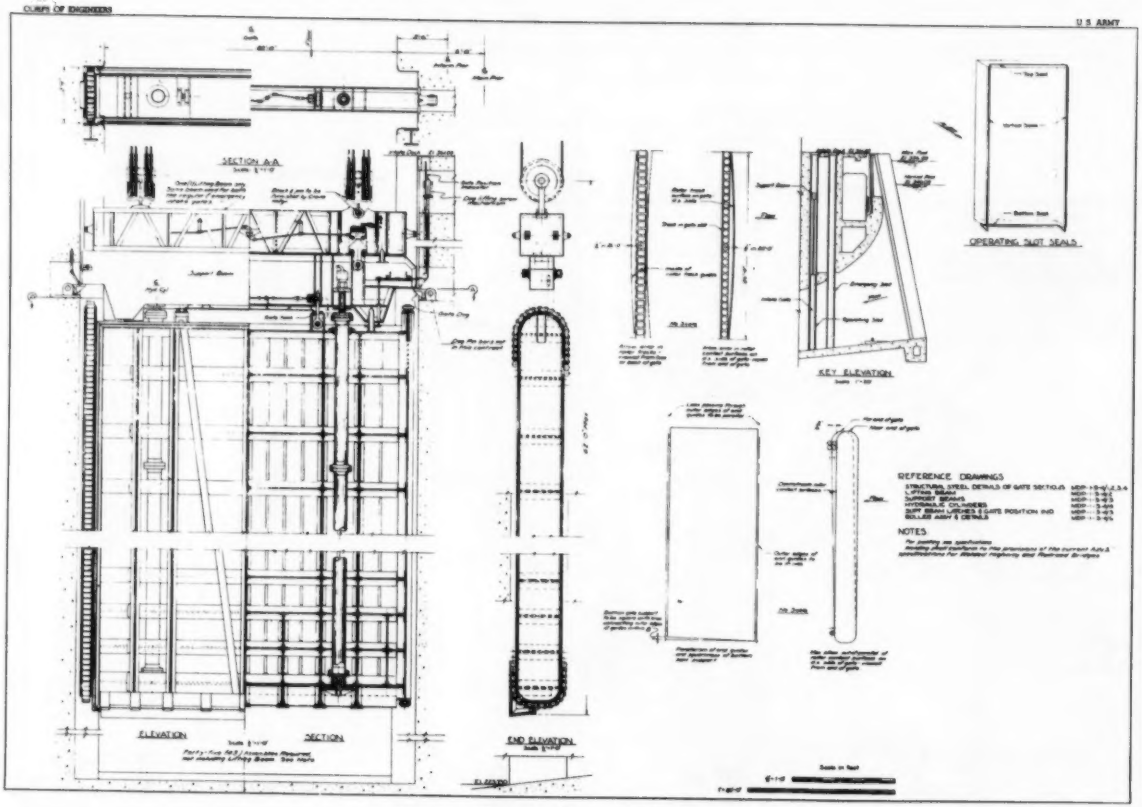


Fig. 5. The McNary Intake Gate

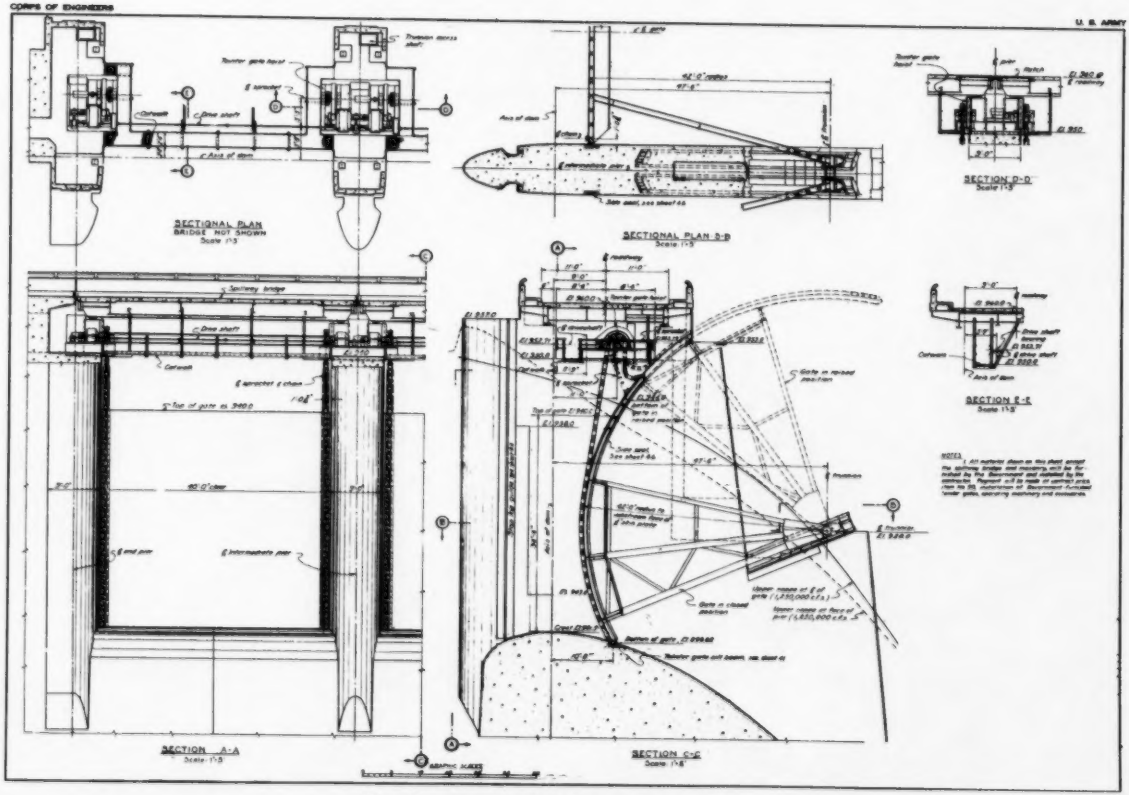


Fig. 6. Typical Tainter Crest Gate

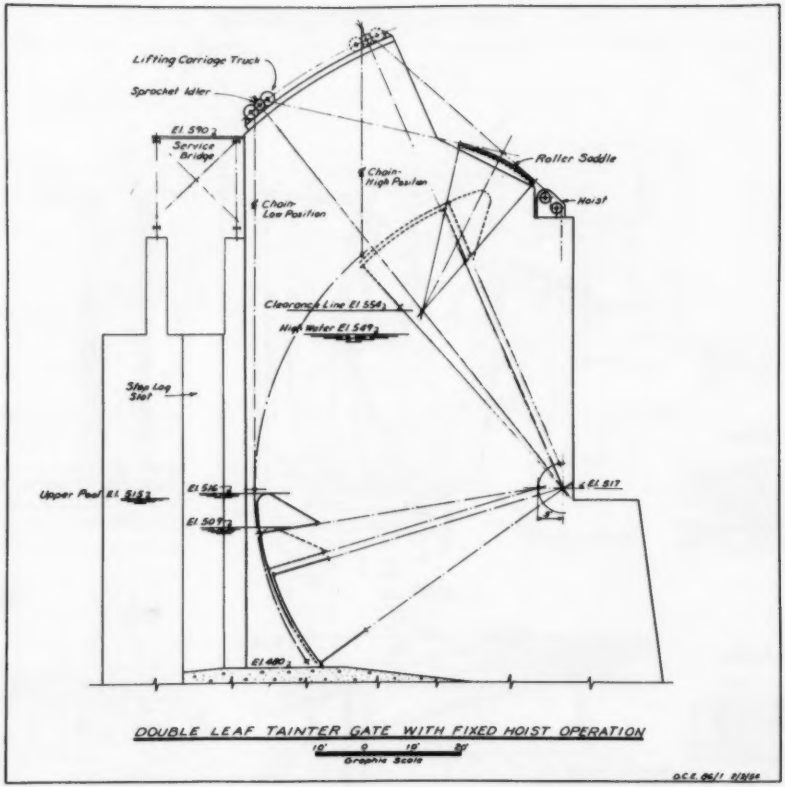


Fig. 7. New Skimming Tainter Gate